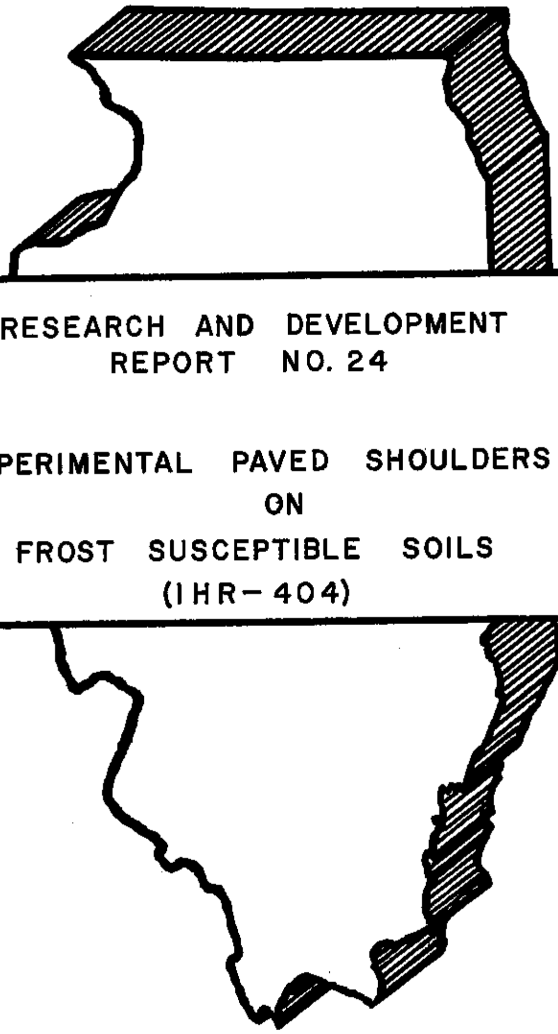
STATE OF ILLINOIS

DEPARTMENT OF PUBLIC WORKS AND BUILDINGS

DIVISION OF HIGHWAYS



RESEARCH AND DEVELOPMENT
REPORT NO. 24

EXPERIMENTAL PAVED SHOULDERS ON FROST SUSCEPTIBLE SOILS

(IHR-404)

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EXPERIMENTAL PAVED SHOULDERS ON FROST SUSCEPTIBLE SOILS
IHR-404
INTERIM REPORT NO. 1

by

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A Research Study

by

Illinois Division of Highways
in Cooperation with
U.S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

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PERFORMANCE OF PAVED SHOULDERS ON FROST SUSCEPTIBLE SOILS

INTRODUCTION

Shoulders that can receive vehicles from the traffic lane at normal operating speeds and permit them to return safely to the pavement are essential features of modern highways. For high-speed, heavily-traveled highways, such as those of the Interstate system, this requires that the shoulders be durable and capable of supporting fairly frequent incursions under all conditions of weather.

Initially, a shoulder consisting of a granular base covered with a bituminous surface treatment was believed adequate for high-speed and high-volume travel conditions in Illinois. Experience soon made it apparent, however, that these shoulders lacked all-weather stability, and that the maintenance task was a serious problem. The substitution of a stabilized mixture of granular material cemented with asphalt, portland cement, or lime-flyash for base construction, and the substitution of a bituminous mat for the seal coat, were found to correct the situation in most instances, but not in all. The major problem in these latter instances was a differential heave of the shoulder with respect to the pavement and subsequent deterioration of the shoulder structure. Lateral dislocation of the shoulder from the pavement also commonly occurred in these instances.

Typical of the paved shoulders giving poor service were those of an expressway entering Chicago from the southwest (1).[1/] Soon after the opening of this expressway in the fall of 1964, an extreme upward displacement of the paved shoulder with respect to the adjacent portland cement concrete pavement was noted. The vertical displacement was accompanied by some lateral

1/ Numerals in parentheses refer to references listed at conclusion of report.

displacement, by the frequent occurrence of longitudinal cracks about one foot from the pavement edge, and by a considerable amount of random cracking between the longitudinal cracks and the interface of the pavement and shoulder.

Three kinds of material were used in the shoulder base courses on this portion of the expressway: (1) cement-aggregate mixture (CAM); (2) pozzolan-aggregate mixture (PAM); and (3) bituminous-aggregate mixture (BAM). The CAM and PAM bases were surfaced with bituminous concrete; the BAM base was not. Except for slight vertical and horizontal displacements that occurred in the BAM base, the deficiencies were confined to locations where the CAM and PAM shoulder bases had been used. A study of the conditions surrounding the paved shoulder failures indicated that the displacement and attendant distress originated through the exposure of frost-susceptible and expansive materials to excessive amounts of surface water. Several factors seemed to have acted either in combination or separately to aggravate the condition, among them being: (1) an embankment soil especially susceptible to frost expansion when exposed to large quantities of water; also one capable of expansion when exposed to moisture; (2) a subbase material somewhat capable of frost expansion when exposed to water but also capable of serving as a source of free water to be drawn upon by contiguous frost-susceptible materials; and (3) base materials lacking adequate durability when exposed to freeze-thaw cycles in the presence of water or brine.

The value of the investigation that was made of the shoulders of this expressway after failure had taken place was considered to have been limited by the lack of adequate knowledge of many details regarding conditions prevailing prior to the occurrence of the shoulder displacement and deterioration.

The study that is the subject of the present report was undertaken to provide this sort of information as well as information on the behavior of paved shoulders in service.

In the present study, experimentally designed paved shoulders were included in a construction contract on Interstate 80 immediately east of Joliet, Illinois. The construction is identified as Section 99-4-1, Project I-80-4(139)135, Will County, District 1, and located as shown in Figure 1. Construction work was completed during the 1967 season, with the exception of a few minor items including a portion of the joint sealing, final grading of shoulders and roadside slopes, the application of topsoil, and seeding. Sealing of the pavement-shoulder joint was completed on the eastbound lanes in the fall of 1967, and in the westbound lanes in the spring of 1968. The roadway was opened to traffic in January 1968, and all construction work completed in that year.

Numerous items of instrumentation were placed during construction for detailed observations of shoulder behavior. Research observations were made during construction, and have been continued following construction. The study is believed to have yielded some important information to date; however, it must be recognized that some of the interpretations of behavior of what might be a 20-year life span based on less than two years of service may be subject to modification as further experience accumulates.

OBJECTIVES

The major objective of this research is to develop definitive information that will permit the selection from among alternative shoulder pavement designs and materials, those that will afford the best service and overall economy of construction and maintenance. A secondary objective is the development of additional information on the interactions of embankment soils, frost, moisture,

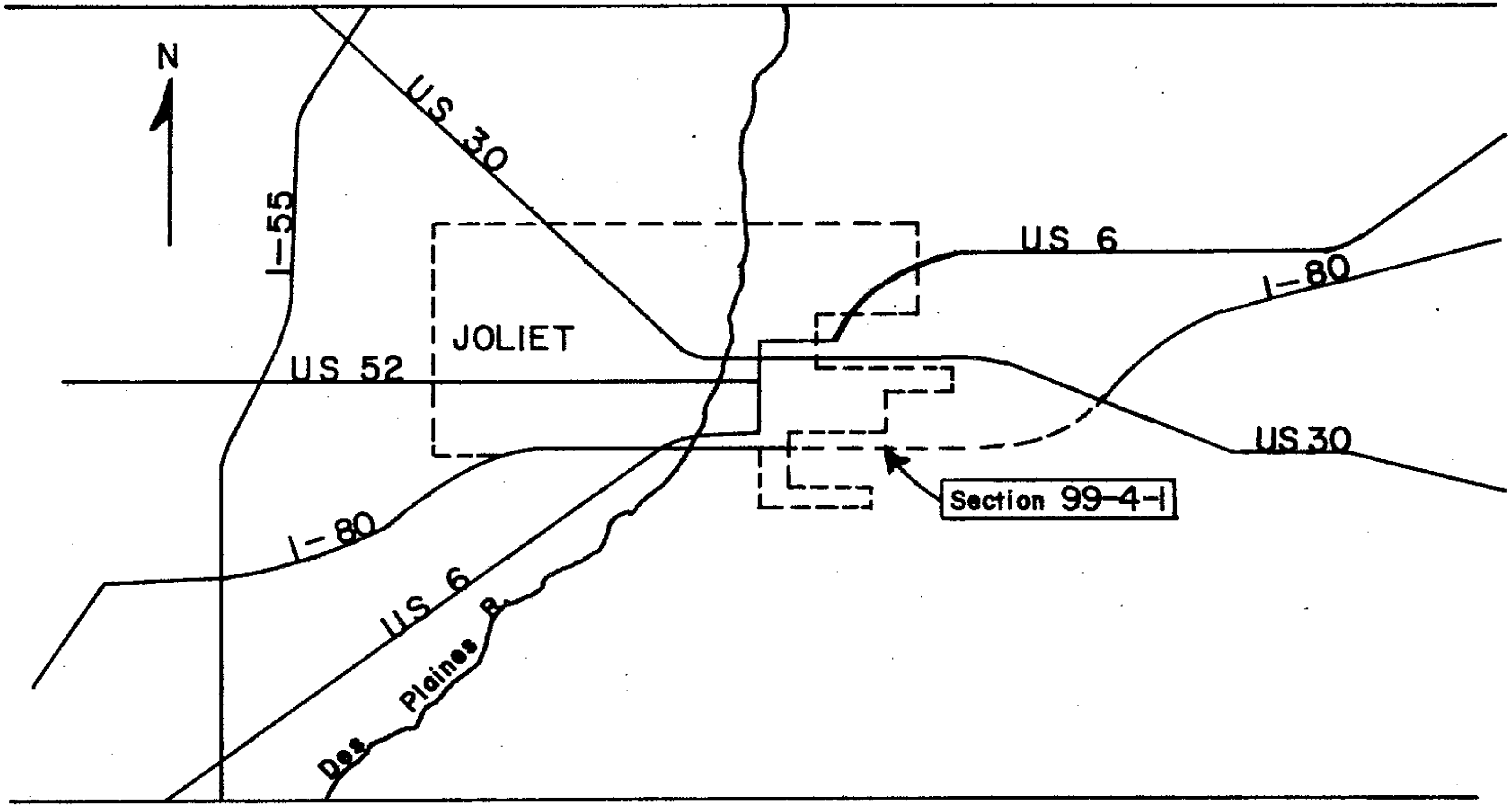


FIGURE 1. Location of Experimental Project.

and deicing operations with shoulder materials and shoulder designs, to help understand the underlying causes of the dislocations and disintegrations that have occurred in the past.

EXPERIMENTAL LAYOUT

Almost all of the 3.9-mile length of construction Section 99-4-1 is included in the experiment. Because of some differences in horizontal and vertical alignments, the individual test sections were placed in three alignment groupings. Group I, at the west end, is within an area of straight horizontal alignment with a fairly steep vertical gradient (up to 3 percent upgrade). Group II, in the central part, is within an area of straight alignment and flat grade. Group III, at the east end, is in an area of horizontal curvature and flat grade where the pavement is superelevated and the crown removed, but with no change in the shoulder slopes.

The principal variables in the experimentation are the shoulder base mixtures, shoulder subbase materials and the use and nonuse of shoulder subbase, and the presence and absence of sealant at the pavement-shoulder interface. Four material types were used in the shoulder bases: (1) bituminous-aggregate mix (BAM); (2) cement-aggregate mix (CAM); (3) Pozzolan-aggregate mix (PAM); and (4) portland cement concrete (PCC). A bituminous-concrete surfacing course was placed on the CAM and PAM bases; the BAM and PCC bases were constructed to serve traffic without additional surfacing. Three types of open-graded aggregates of differing gradation were used as shoulder subbases, and some sections were constructed without subbase. Material details are presented in a following section of the report.

The subbase underlying the pavement was constructed of the same materials as used in the adjacent shoulder base, except that CAM was used in the pavement subbase adjacent to the PCC shoulder structures.

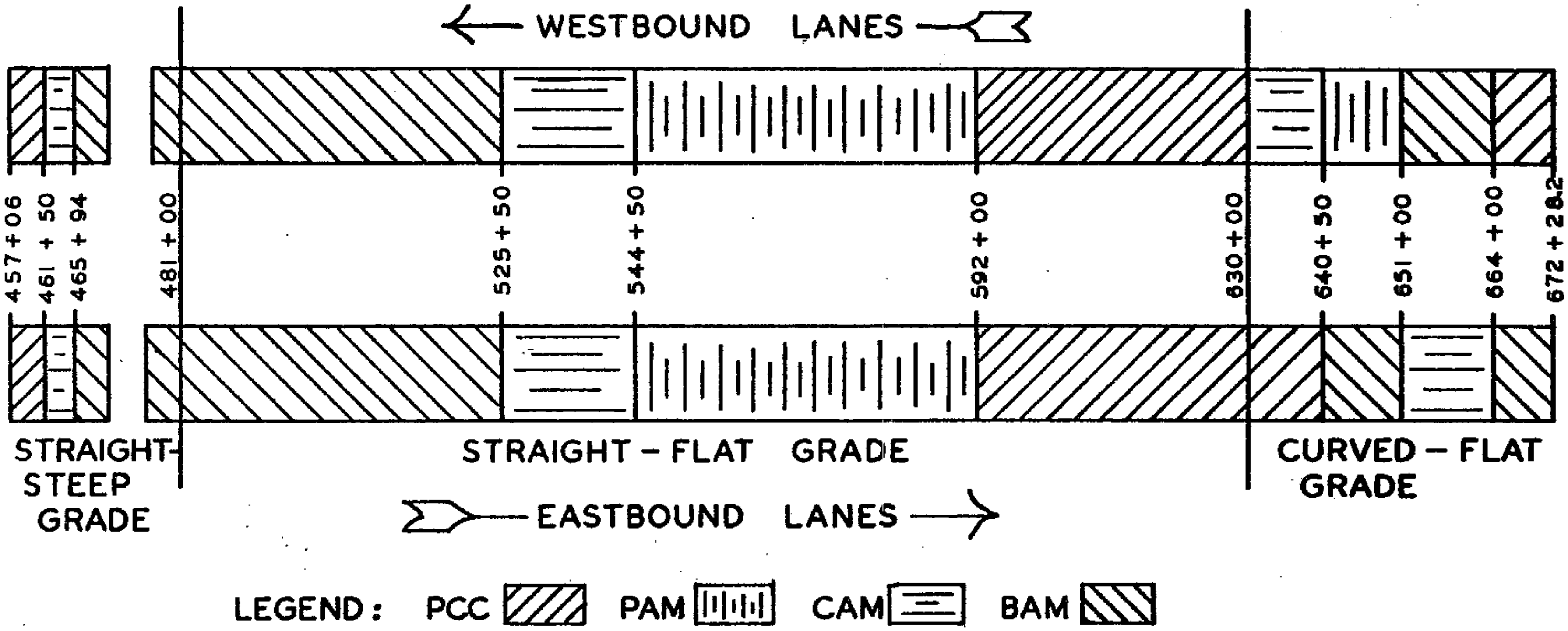
All of the test combinations are included at least once in alignment Group II, and as many of the combinations as possible are repeated in Groups I and III. The test sections vary in length from about 450 feet to over 1600 feet. The layout was planned to facilitate construction as much as possible, particularly with reference to placement of materials. The locations of the shoulder types are shown in Figure 2. The makeup of each test section, together with the location of the instrumentation, is shown in Table 1.

Instrumentation was installed during construction to provide data on vertical pavement and shoulder movements and on frost penetration. Embankment soil moisture contents and densities are being measured by the nuclear method. Additional supplemental information is being obtained through condition surveys and roughness surveys to help evaluate the performance of the shoulders.

SOILS

The embankment materials at the experiment site are mostly fine-textured A-4, A-6, and A-7-6 soils. The physical characteristics shown in Table 2 for samples taken at settlement plate locations are representative of those of the soils throughout the project. The material is principally glacial drift of Wisconsinan Age (2) overlying dolomitic limestone bedrock. Although the glacial drift is relatively thin in the area, the bedrock appeared in the zone of construction operations in only one instance. This is between Stations 654 and 664 where the pavement structure inclusive of subbase was constructed on a foot or more of crushed stone placed directly on bedrock.

These soils are representative of those that have been in the past adversely affected by freeze-thaw action in Illinois.



(SCALE: 1 INCH = 2200 FEET)

I-80, SECTION 99-4-1, WILL COUNTY

FIGURE 2. Location of Shoulder Types in Experimental Area.

TABLE 1

TEST SECTIONS AND INSTRUMENT LOCATIONS

Test Sections From	Test Sections To	Joint Sealed	Shoulder Type 1/ Eastbound	Shoulder Type 1/ Westbound	Instrumentation Station	Instrumentation Type 2/
			Alignment Group I			
457+06	459+28	Yes	PCC/B	PCC/E		
459+28	461+50	No	"	"		
461+50	463+72	Yes	CAM/B	CAM/E	462+50	S.P.
463+72	465+94	No	"	"	464+50	S.P.
465+94	468+16	Yes	BAM/B	BAM/E		
468+16	470+38	No	"	"		
470+38	476+34		Rowell Avenue Bridge			
476+34	479+67	Yes	BAM/B	BAM/E		
478+67	481+00	No	"	"		
			Alignment Group II			
481+00	493+50	Yes	BAM/B	BAM/E	487+00	S.P.
493+50	506+00	No	"	"	495+00	S.P., F.G.
506+00	515+75	Yes	BAM/C	"		
515+75	525+50	No	"	BAM/A		
525+50	530+25	Yes	CAM/C	CAM/A		
530+25	535+00	No	"	"		
535+00	539+75	Yes	CAM/B	CAM/E	537+50	S.P.
539+75	544+50	No	"	"	542+00	S.P.
544+50	551+75	Yes	PAM/B	PAM/E	548+00	S.P., F.G.
551+75	559+00	No	"	"		
559+00	575+50	Yes	PAM/C	PAM/A	553+50	S.P.
575+50	592+00	No	"	"		
592+00	603+50	Yes	PCC/C	PCC/A	619+00	S.P.
603+50	615+00	No	"	"		
615+00	622+50	Yes	PCC/B	PCC/E		
622+50	630+00	No	"	"	626+00	S.P., F.G.
			Alignment Group III			
630+00	632+62	Yes	PCC/B	CAM/E		
632+62	635+20	No	"	"		
635+20	637+87	Yes	PCC/E	CAM/B		
637+87	640+50	No	"	"		
640+50	643+12	Yes	BAM/E	PAM/B		
643+12	645+75	No	"	"		
645+75	648+37	Yes	BAM/B	PAM/E	647+00	S.P.
648+37	651+00	No	"	"	649+50	S.P.
651+00	653+62	Yes	CAM/R	BAM/R		
653+62	656+25	No	"	"		
656+25	660+12	Yes	CAM/B	BAM/B		
660+12	664+00	No	"	"		
664+00	666+00	Yes	BAM/E	PCC/B		
666+00	668+00	No	"	"		
668+00	670+14	Yes	BAM/B	PCC/E		
670+14	672+28	No	"	BAM/E		

1/ Single letter indicates the type of subbase (A, B, or C), earth subgrade (E), or crushed stone over bedrock (R).

2/ S.P.= settlement plate installation, eastbound and westbound;
F.G.= frost gage installation, eastbound and westbound.

TABLE 2

PHYSICAL PROPERTIES OF SOILS AT SETTLEMENT PLATE LOCATIONS

Station	Eastbound			Westbound		
	Percent finer than .005 mm	Plasticity Index (%)	AASHO 1/ Soil Class	Percent finer than .005 mm	Plasticity Index (%)	AASHO Soil Class
462+50	22	15	A-6(3)	27/51	12/15	A-6(4) A-6(10)
464+50	38	9	A-4(8)	51	15	A-6(10)
487+00	48	30	A-7-6(16)	50	12	A-7-6(10)
495+00	57	20	A-7-6(12)	50/53	19/15	A-7-6(12) A-6(10)
537+50	42	15	A-6(10)	41	12	A-6(9)
542+00	40	16	A-6(10)	47	21	A-6(13)
548+00	46	9	A-6(8)	43	20	A-6(12)
553+50	36	14	A-6(9)	47	15	A-6(10)
619+00	56/50 2/	27/17	A-7-6(16) A-6(11)	54	18	A-6(11)
626+00	50/42	18/25	A-6(12) A-7-6(14)	49	25	A-6(14)
647+00	58	16	A-6(10)	50	14	A-6(10)
649+50	14	4	A-4(3)	29	12	A-6(7)

1/ Bracketed number is the group index
2/ Double numbers represent two different soils. The top number represents the upper soil layer.

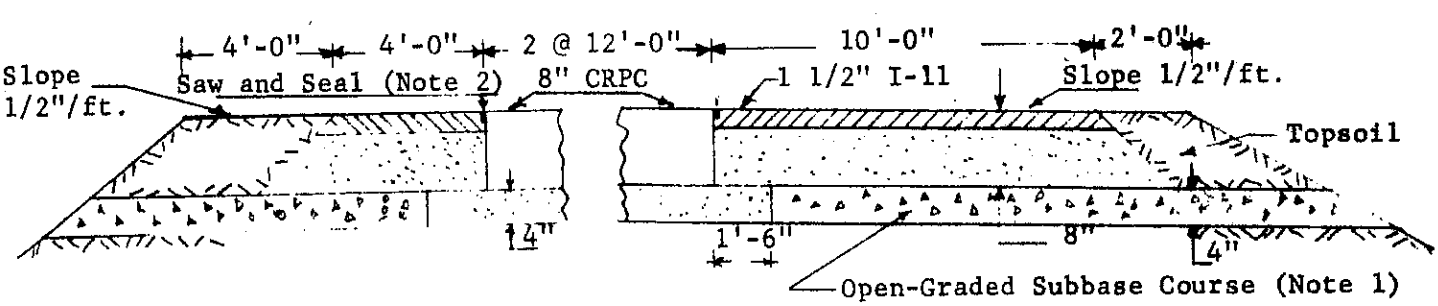
STRUCTURAL DESIGN OF SHOULDERS

The structural components of the experimental shoulders and their dimensions are shown in Figure 3. The outside shoulders are 10 feet wide and the median shoulders are 4 feet wide. The CAM and PAM base courses are of uniform thickness (6 1/2 inches) surfaced with 1 1/2 inches of bituminous concrete. The BAM, and PCC shoulders taper somewhat from approximately 8 inches thick at the pavement edge. The 4-inch thick open-graded subbase, where used, extends from the edge of the pavement subbase to the shoulder slope. It is left open on the shoulder slope to facilitate free drainage. The shoulders are sloped at the rate of 1/2 inch per foot. The PCC shoulders are tied to the pavement, have 6-foot-long rumble strips at 60-foot intervals, and dummy-groove transverse joints at 20-foot intervals. These and other features are shown in Figure 3.

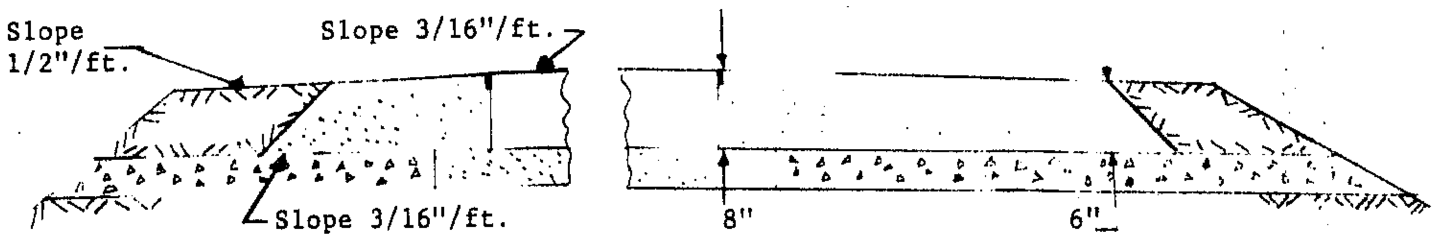
The mainline pavement in the test area is continuously reinforced portland cement concrete, 8 inches thick, with a 4-inch thickness of subbase of the same kind of material as that used in the adjoining shoulder, except that CAM was used as the pavement subbase in locations adjacent to the portland cement concrete shoulders.

SHOULDER MATERIALS

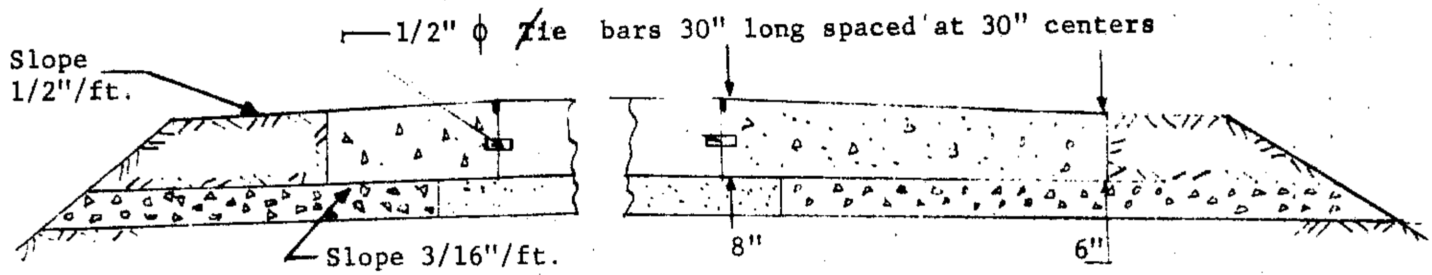
Bituminous-aggregate mixture (BAM).--The bituminous aggregate mixture that was used in the shoulder and pavement subbase construction is a dense-graded material composed of crushed stone and paving asphalt (Grade 200-300). The mix was designed to contain 4.5 percent asphalt by weight of the total mixture, except that 5.0 percent asphalt was to be used in the shoulder surface lift.



CAM or PAM



BAM

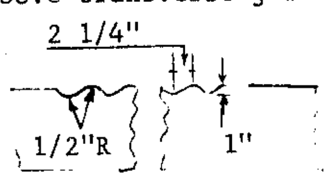


PCC

Note 1. Open-Graded Subbase Course used on approximately one half of test sections; shoulder structure placed on regular embankment soil elsewhere.

Note 2. Shoulder-pavement joint sawed to depth of 3/4" and width of 1/2" and sealed with hot-poured rubber asphalt joint-sealing compound on one half of each test section.

Note 3. Rumble strips on PCC shoulders 6'-0" long, full width, at 60' spacing. Dummy-groove transverse joint every 20'.



Rumble Strip Design

Figure 3. Design of experimental shoulders

Gradation specification limits under which the aggregate was furnished, and a typical aggregate gradation, are as follow:

Sieve Size	Specification Limits (percent passing)	Typical Gradation (percent passing)
1 in.	100	100
1/2 in.	60-100	82
No. 4	40-65	48
No. 8	25-55	35
No. 200	5-15	8

The minus No. 40 sieve fraction had little or no plasticity.

The mixture was prepared in a hot-mix plant and delivered to the jobsite at temperatures specified to range between 225°F and 325°F.

Marshall tests of a sample of the bituminous-aggregate mixture containing 4.5 percent asphalt taken at the jobsite produced the following results:

Stability (lb.)	2485
Flow (1/100 in.)	11

Cement-aggregate mixture (CAM).-- The cement-aggregate mixture used both as pavement subbase and as shoulder base was composed of Type 1 cement and a blend of crushed stone and stone screenings. Specification limits for the gradation of the aggregate and a typical gradation of the material furnished to meet these limits are as follow:

Sieve Size	Specification Limits (percent passing)	Typical Gradation (percent passing)
1 in.	100	100
1/2 in.	60-100	87
No. 4	55-75	57
No. 8	40-65	42
No. 200	5-12	10

Blending stone screenings with the available crushed stone material was necessary to produce the desired fineness at the No. 4 and No. 8 sieve levels.

Previous experience had shown that mixtures of coarser gradation lacked durability at normal cement contents.

A cement content of 5.2 percent of the dry weight of the aggregate was established for the mixture based on standard short-cut soil cement mixture design procedures. At 4, 6, and 8 percent cement by weight, laboratory 7-day compressive strengths of 648, 1460, and 2727 psi respectively were recorded. The maximum density of the mixture was determined to be 142 pcf at an optimum moisture content of 7.5 percent under AASHO T99 (Method C).

The mixture was prepared in a batch-type mixer at a central mixing plant and trucked to the jobsite.

Pozzolan-aggregate mixture (PAM).--Wet-bottom boiler slag was combined with lime and flyash (and water) to produce the pozzolan-aggregate mixture.

Specification limits for the boiler slag, and a typical gradation, are as follow:

Sieve Size	Specification Limits	Typical Gradation
	(percent passing)	
No. 4	80-100	97
No. 10	55-90	77
No. 40	0-25	13
No. 200	0-10	3

The flyash was specified to meet the requirements of ASTM Designations C 379 or C 342 with an allowable 10 percent maximum loss on ignition. At the time of mixing, the flyash was required to meet the following gradation requirements in dry sieving:

Sieve Size	Minimum Passing (percent)
1/2 in.	100
3/8 in.	95
No. 10	75

The moisture content of the dampened flyash at mixing was required not to exceed 35 percent.

Both the slag and flyash were furnished from a nearby power plant.

The lime was furnished to comply with the requirements of ASTM Designation: C 207, "Hydrated Lime for Masonry Purposes, Type N," except that there was to be a minimum of 90 percent total calcium and magnesium oxides (nonvolatile basis), and the calcium oxide and magnesium contents on an as-received basis were not to exceed 5 percent.

The pozzolan-aggregate-mixture composition specification, and the job mix formula were as follow:

Component	Proportion	
	Specification (percent)	Job-Mix Formula (percent)
Slag	56-78	73.0 $\pm$ 2.0
Flyash	15-30	24.0 $\pm$ 1.5
Lime	2-4	3.0 $\pm$ 0.3

The optimum moisture content for a mixture meeting the job-mix formula, to produce a maximum dry density of 135 pcf when tested in accordance with AASHO Designation T 180 (Method C), except that three lifts were used instead of five, was determined to be 9 percent. The moisture content of the mixture at compaction was required to be within 85 to 110 percent of this moisture content.

In designing the mixture, test cylinders were prepared at optimum moisture content and compacted in accordance with AASHO Designation T 180 (Method C) with the previously described modification. Mixtures with lime contents of 2, 3, and 4 percent were used in the preparation of the cylinders. The specimens at the various lime percentages were placed in watertight containers immediately after molding and heated to 100°F $\pm$ 3° for 7 days. At the end of

7 days, the test cylinders were removed from the container, allowed to cool to room temperature, soaked in water for 4 hours, removed from the water, capped, and broken to determine compressive strengths. The design lime content was established to meet a requirement that the minimum average compressive strength be no lower than 400 psi and that no individual test be lower than 300 psi.

The materials were mixed at a central mixing plant (pugmill type) and trucked to the jobsite for spreading and compacting.

Portland cement concrete (PCC).--The portland cement concrete mixture for the PCC shoulder was specified to meet the requirements of the Illinois standard specifications for portland cement concrete pavement construction. Type 1A cement was used. The materials in proportion were combined with water in a central mixing plant and wet-batched to the jobsite in trucks.

Bituminous concrete surfacing (Class I).--A 1 1/2-inch surface course of bituminous concrete mixture, fine dense-graded aggregate type, was placed over the CAM and PAM shoulder bases. The mixture, consisting of crushed limestone coarse aggregate, sand, limestone dust, mineral filler, and a paving grade asphalt, was required to meet the Illinois standard specifications for Class I bituminous concrete.

Shoulder subbase materials.--The experiment provided for the shoulder bases to be placed on subbases composed of aggregates furnished under three differing gradation specifications, as well as on the natural subgrade. The three gradation specifications, all commonly used for other purposes in Illinois, and typical analyses of materials furnished under them, are shown in Table 3.

The intent of the subbase material study was to determine which of the three materials furnished under the three differing gradation specifications

TABLE 3

SPECIFIED GRADATION LIMITS AND TYPICAL
SIEVE ANALYSES FOR SHOULDER SUBBASE AGGREGATES

	Subbase Material					
	Type A		Type B		Type C	
Sieve Size	Spec. Limits (percent passing)	Typical Analysis (percent passing)	Spec. Limits (percent passing)	Typical Analysis (percent passing)	Spec. Limits (percent passing)	Typical Analysis (percent passing)
1 1/2 in.	-	-	97-100	100	100	100
1 in.	100	-	60 ~~50~~-95	95	90-100	99
1/2 in.	90-100	100	10-30	23	25-60	40
No. 4	50-100	99	0-5	4	0-10	8
No. 16	30-80	61	-	-	-	-
No. 50	0-20	15	-	-	-	-
No. 200	0-3	3	-	-	-	-

would provide the best combination of manageability during construction and drainability. A washed sand very similar to that used in concrete mixtures was furnished to meet the Type A specification as shown in Table 3. Crushed stones were furnished to meet the Type B and Type C specifications. The Type B specification is the Illinois specification for the smaller of two sizes of aggregate (Size B) for paving concrete.

Shoulder joint sealant.--The sealant used at locations where the experimentation required cutting and sealing the joint at the pavement-shoulder interface was a hot-poured rubber-asphalt compound typical of those meeting high-standard specifications with respect to bond, resilience, and impact.

EMBANKMENT CONSTRUCTION

Embankment construction on the experimental project began in September 1966 and was mostly completed prior to the close of the 1966 construction season. The remaining embankment work, consisting of the completion of a high fill west of the Rowell Avenue bridge at the west end of the project and a portion of the westbound embankment between Stations 476+50 and 520+00, was completed early in 1967. The rough grade was left slightly higher than final subgrade elevation. Standard construction controls were exercised during embankment construction.

In addition to the regular moisture-density control tests made during embankment construction, moisture and density measurements also were made in the upper one-half foot of the embankment just prior to undertaking construction of the shoulder structures. The results of these tests are tabulated in Table 4. It will be noted in the table that in many instances the fine-grained soils on which the shoulder structures were placed had moisture contents well below optimum, but relatively high densities, at the time these structures were placed.

TABLE 4

SHOULDER MOISTURE-DENSITY ~~STUDY~~

Station	Shoulder Design [1/]	Optimum Moisture	Maximum Density	In-Place Moisture	In-Place Density
		(%)	(pcf)	(%)	(pcf)
			Eastbound		
461+50	PCC/B	13.6	119.9	12.9	120.3
465+94	CAM/B	-	-	8.7	121.3
470+38	BAM/B	-	-	11.7	124.0
506+00	BAM/B	-	-	9.5	124.5
525+50	BAM/C	-	-	8.3	120.7
535+00	CAM/C	-	-	6.5	127.9
544+50	CAM/B	12.7	121.1	7.8	126.5
559+00	PAM/B	-	-	11.6	117.8
592+00	PAM/C	13.2	120.0	10.4	119.9
615+00	PCC/C	12.7	122.1	9.4	117.5
635+25	PCC/B	-	-	9.7	116.7
640+50	PCC/E	26.2	90.2	10.5	114.5
645+75	BAM/E	-	-	7.6	118.5
651+00	BAM/B	-	-	7.8	118.5
656+25	CAM/B	-	-	8.7	117.8
664+00	CAM/E	-	-	7.2	123.3
668+00	BAM/E	-	-	11.2	113.8
			Westbound		
461+50	PCC/E	-	-	12.2	122.8
465+94	CAM/E	11.6	124.8	8.7	123.3
470+48	BAM/E	-	-	10.7	120.0
515+00	BAM/E	12.2	122.9	6.8	117.0
525+50	BAM/A	-	-	6.6	126.6
535+00	CAM/A	-	-	6.6	127.6
544+50	CAM/E	-	-	7.9	119.4
559+00	PAM/E	-	-	6.5	120.6
592+00	PAM/A	13.8	117.8	10.4	120.6
615+00	PCC/A	-	-	9.5	115.0
630+00	PCC/E	15.8	112.7	9.1	120.4
641+50	CAM/B	-	-	8.8	120.5
645+75	PAM/B	-	-	10.0	115.0
651+00	PAM/E	-	-	6.6	118.3
656+25	BAM/E	-	-	5.3	123.8
664+00	BAM/B	-	-	5.7	124.6
668+00	PCC/B	12.0	125.1	7.8	125.8
672+28	PCC/E	-	-	6.4	128.5

1/ Letters A, B, and C are subbase types; letter E designates earth subgrade.

PAVEMENT SUBBASE CONSTRUCTION

Construction of the stabilized subbases for the pavement began in June 1967. This work was carried on concurrently with fine grading of the earth subgrade. Both fine grading of the subgrade and placement of the stabilized subbase material were done with a CMI Autograde which incorporates automatic control of both its vertical and horizontal movements. A hopper is attached to the front of the machine to receive material for spreading.

The prepared subbase mixtures (BAM, CAM and PAM) were unloaded directly into the CMI machine hopper from the trucks delivering them from the central plants where they were produced to the jobsite. They were then spread by the CMI machine to the required width and to slightly greater than the required thickness.

After a convenient length of subbase material was placed and compacted, the CMI Autograde was backed up and then moved forward to trim the surface at the required grade (± 1/8 in.). The length of subbase that could be constructed between trimming operations was limited by the requirements of the specifications and by the characteristics of the subbase materials. Specifications for the CAM required that it be placed and compaction started within one hour following the addition of water to the mix, and that compaction be completed within two hours after the addition of water, with shaping of the surface to take place near the completion of initial compaction. It was also required that uncompacted and unfinished mixtures not remain undisturbed for more than 30 minutes. To fulfill these requirements, the mixing plant and truck operations were halted several times during the day while the CMI machine was backed and moved forward in the shaping operation. The BAM and PAM materials were shaped once each day for the entire length of placement toward the close of work for the day.

Fine grading and subbase placement operations were interrupted by rainy weather a number of times. Softening of the completed earth subgrade at the outer margins of the work area on which the CMI machine was dependent for support contributed significantly to the down time.

Most of the fine grading and stabilized subbase construction was completed by the latter part of July 1967. The final section of subbase was placed west of the Rowell Avenue bridge in September 1967. The September 15 cutoff date for the use of PAM was waived and extended to October 1 to permit placing PAM in this area.

SHOULDER CONSTRUCTION

Shoulder construction took place during the period of August-November 1967, overlapping slightly the construction of the continuously reinforced concrete pavement during July and August 1967.

The earth subgrade was prepared to receive the shoulder materials by shaping with a motor grader, compacting with rollers, and reshaping with the grader as necessary to meet final grade (Figure 4).

Shoulder subbase construction.--The subbase materials where used were placed in windrows on the subgrade by trucks equipped with bottom dumps. The aggregates were spread from the windrows with a motor grader and compacted with a rubber-tired roller. The Type A (washed sand) material required the addition of moisture for adequate compaction. Final trimming of this material was accomplished with a blade operated from the pavement (Figure 5). The Type A material washed badly during rains and needed much reworking before the base material was placed on it (Figure 6). The Type B and Type C crushed stone aggregates consolidated little during compaction, and required no reworking prior to base construction.

originals in March 1972 report

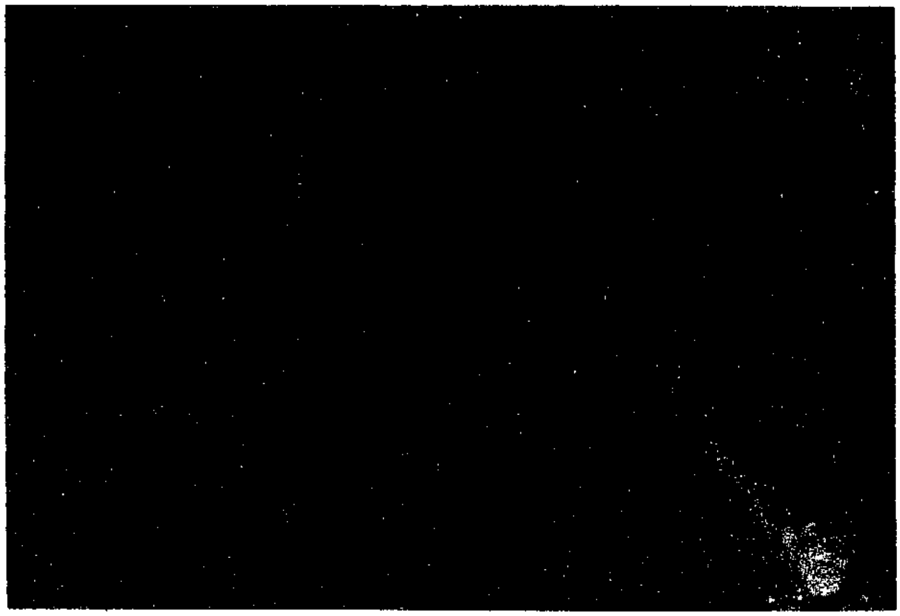


Figure 4. Finished subgrade ready to receive subbase (canvas strips in foreground are for sampling purposes).

Figure 5. Grading Type A aggregate in preparation for receiving the base course.

Figure 6. Type A aggregate tended to saturate with rainfall and wash badly during rains.

Figure .. Shoulder paving machines worked off the pavement.

Shoulder base construction.--The BAM, CAM, and PAM for shoulder base were placed by machines operating on the pavement (Figures 7 and 8). They were placed in two lifts of approximately equal thickness.

Each BAM lift was compacted with a rubber-tired roller followed by a steel-wheeled roller. The lower lift was compacted to meet a specified minimum requirement of 85 percent of theoretical density; the upper lift to meet a specified minimum of 90 percent of theoretical density.

Each of the two layers of CAM was compacted with a steel-wheeled roller followed by a vibratory compactor (Figure 9). The surface of the lower lift was scarified prior to placing of the upper lift, and maintained in a moist condition until the upper lift could be placed. Compaction to at least 94 percent of standard dry density within two hours of the addition of water was specified for the CAM. All work within a section of CAM placed was required to be completed within a day's time, including final shaping and compaction. It also was required that uncompacted and unfinished CAM not remain undisturbed for more than 30 minutes. Spraying of the finished surface with water until application of the curing coat also was required.

The two layers of PAM each were compacted with a steel-wheeled roller followed by a vibratory compactor. Special care was required on the part of the operator of the vibratory compactor to prevent shoving and rutting of the material being compacted. The surface of the lower lift was scarified and kept moist until the upper lift was placed. Compaction of each lift to at least maximum density as determined by a somewhat modified version of AASHO T 180 (Method C) was required for each lift and immediately adjacent to the pavement structure, except that a minimum of 97 percent was permitted away from the pavement structure in lifts placed on earth subgrade. The upper

Figure 8. Placing the top lift of the CAM base course.

Figure 9. Compacting the final CAM base lift.

lift in each increment of base placed was required to be placed and given its final finish on the same day the lower lift was placed. The surface was to be kept moist until the curing coat was applied.

Curing the CAM and PAM.--The finished base courses of PAM and CAM were sealed with a coat of liquid asphalt (RC-2) which was applied at the rate of 0.15 gal./sq. yd. on the PAM and 0.20 gal./sq. yd. on the CAM. The curing coat was applied on the CAM the same day of the finishing operation, and on the PAM the day following the finishing operation.

Surfacing the CAM and PAM.--The PAM and CAM shoulders were surfaced with a 1 1/2-inch thick wearing course of bituminous concrete (Class I) placed with a Barber Greene spreader and compacted with rubber-tired and steel-wheeled rollers. The 4-foot median shoulders and the 10-foot outside shoulders were built by the same methods. The compaction operation on a median shoulder is shown in Figure 10.

PCC shoulder construction.--The PCC shoulders were placed with a slipform pulled by a heavy rubber-tired tractor operating on the pavement (Figure 11). Shoulder concrete was wet-batched from a central mixing plant to the jobsite in agitator trucks. In the finishing operation, dummy-groove transverse joints were hand-troweled 1 1/2 inches deep at 20-foot intervals. Six-foot rumble strips were floated in with a corrugated float at 60-foot intervals. The surface of the concrete was textured with a burlap drag.

No. 5 deformed steel bars, 30 inches long and bent in the middle, were fastened at 30-inch intervals to the mainline pavement reinforcement to be in place for bending outward following the pavement construction to tie the PCC shoulders to the pavement. A cardboard cover was used on the portion of the bars to be bent outward. These bars became dislocated in varying degree

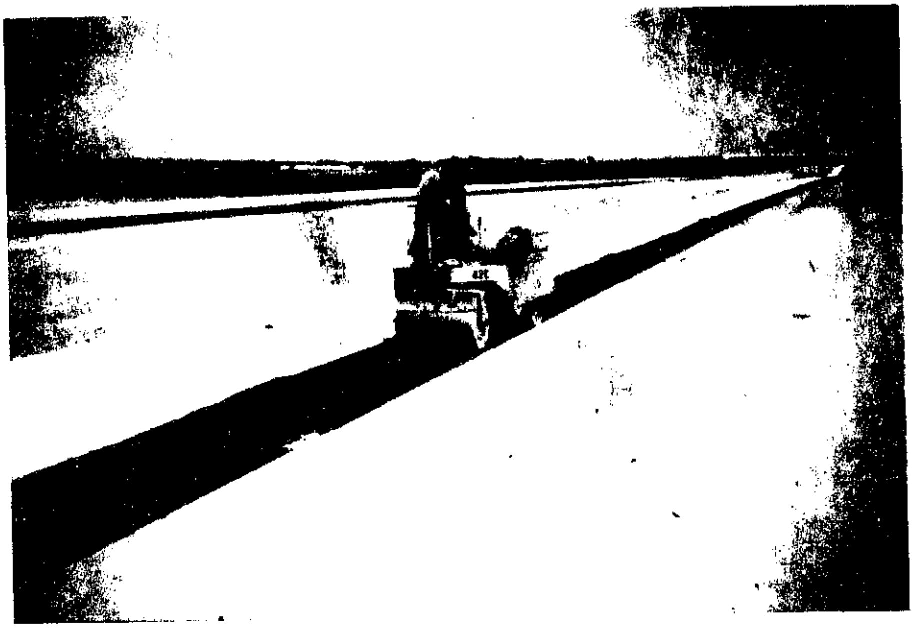


Figure 10. Compacting the bituminous concrete surface on PAM in the median shoulders.

Figure 11. Placing the portland cement concrete shoulders with a slipform paver.

during the slipform process that was used to place the mainline pavement concrete, and could be found only with great difficulty after paving. They were finally replaced in the hardened concrete with No. 4 smooth, hooked steel bars, 15 inches long, anchored in the pavement to a depth of 2 inches (Figure 12).

TOPSOIL PLACEMENT

Topsoil was placed on the paved shoulders in a windrow, and bladed onto the shoulder berm and slope (Figure 13). Final grading of the shoulder slope re-exposed the subbase on the slope to allow drainage from beneath the shoulder to take place.

JOINT SEALING

A saw cut was made in the pavement-shoulder joint of the west half of each test section to a depth of 3/4 inch and to a width of 1/2 inch, and the cuts sealed with the hot-poured rubber-asphalt sealing compound (Figure 14). No cut was made and no seal was applied in the pavement-shoulder joint in the east half of each test section.

SPECIAL CONSTRUCTION PROBLEMS

During the progress of the shoulder construction work, various problems were encountered that seemed mostly related to the construction materials. Some are susceptible to correction and can be avoided in future work. Others are inherent in the individual materials involved and do not appear readily susceptible to change.

The washed sand that was furnished to meet the Type A subbase material specification was difficult to compact. It supported the compaction equipment when moistened, but after drying lost its density when disturbed. It was

Figure 12. Steel bars were turned into anchors set in the pavement edge to replace lost tiebars.

Figure 13. Topsoil windrow on the shoulder was bladed onto the shoulder berm.

Figure 14. Sawed joints in west half of each test section were sealed with a hot-poured elastic sealant.

especially troublesome in the median shoulders where it gave way under the 4-foot rollers and allowed them to tip sideways. As mentioned earlier, the Type A material also washed badly during rains, and required reworking before placement of the next structural layers.

Variability in the moisture content of the PAM associated with both weather and water control problems at the mixing plant caused compaction problems on the roadway. The early cutoff date of September 15 for the use of PAM also became a problem on this particular project. The CAM handled well, but difficulties were experienced in obtaining the required density. The BAM tended to roll outward during compaction and ultimately was found to have become consistently thinner than plan thickness.

SHOULDER COSTS

To obtain some knowledge of the costs of the various shoulder types included in the experiment, analyses were made of (1) unit bid prices and (2) estimated contractor costs. While the results are of interest, it is important to recognize their probably atypical character with reference to normal construction projects.

For estimating contractor costs, the resident engineer on the project maintained daily tabulations showing the pay items on which the contractor was working, the amounts and types of equipment and labor involved in both field and plant operations, the amounts of time that labor and equipment were used for particular pay items, the costs of materials, and the amounts of daily production. The tabulated information was analyzed by estimators in the central office of the Division of Highways, and final cost figures were determined through the application of prevailing wage and equipment rental rates for the area, material costs as quoted by the suppliers, standard overhead costs, and profit factors.

The principal results of the analyses are shown in the bar chart of Figure 15 developed from costs summarized on a per mile basis for shoulders adjacent to one pavement. It is emphasized that the per mile costs that are shown for the various shoulder designs and types must be recognized as applying to experimental construction, and in some instances to types of construction unfamiliar to the contractor. Under these unique conditions, the cost figures and cost relationships that are indicated may not be truly representative of conditions that might exist in normal situations.

Insofar as the contract costs to the State are concerned, it will be noticed that less than $5,000 per mile separates the four shoulder types, with the PCC shoulders costing the most and the PAM shoulders costing the least. This is true for both the shoulders with subbase and those without subbase. The use of subbase will be seen to have added a little over $7,000 per mile to the contract prices.

For this single project, the cost study figures favor BAM construction. The cost that is indicated for the CAM construction, which is considerably higher than the cost of constructing any of the other types, seems singularly high and at variance with the situation that existed in Illinois a few years ago when alternate bids were being invited on CAM and BAM shoulders.

It will be noted also in the figure that the use of Types B and C (coarse aggregate) subbases adds about $7,000 to $8,000 per mile to the computed construction costs. The cost of the Type A (sand) subbase that proved to be impractical because of construction problems was higher than that for the Types B and C subbases, and was not included in the development of the chart.

INSTRUMENTATION

Settlement plates were installed during construction for use in measuring vertical movements of all structural components, including the upper portion

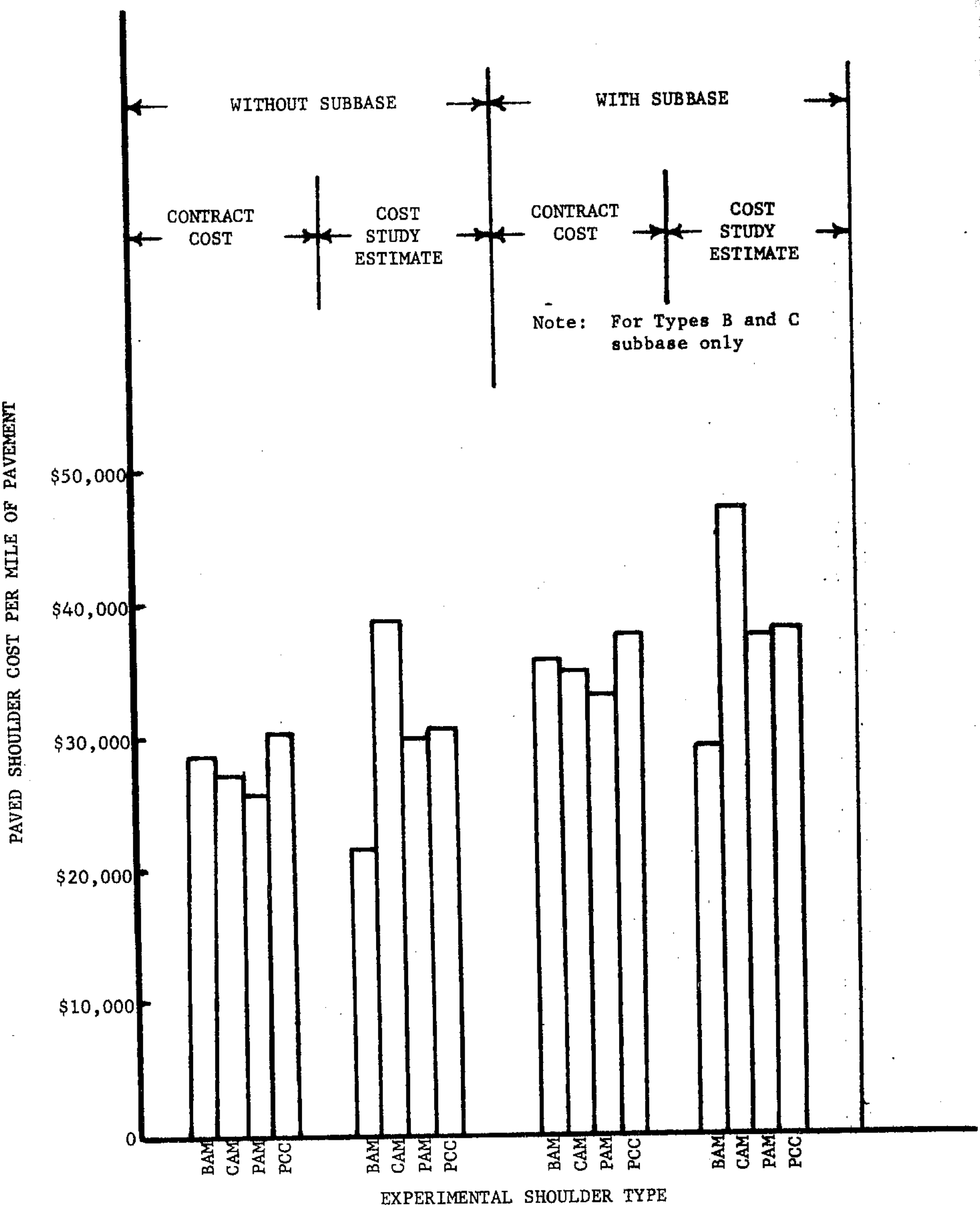


Figure 15. Shoulder construction costs on experimental project

of the embankment soil. Thermocouples were installed for the measurement of temperatures as well as to indicate frost penetration. Frost penetration also is being measured through the use of electronic resistance gages and Gandahl gages. Moisture is being monitored to depths of five feet below the surface by means of nuclear gages(3). Pavement and shoulder roughnesses are being measured with a BPR-type roughometer, cores are being taken and studied, and condition surveys are being made to provide further information.

A typical settlement plate installation in a shoulder with a subbase is shown in Figure 16. The number of plates differs between installations, depending on the number of structural components. Sets of plates were installed beneath the outer pavement edge and under the outer shoulder in the eastbound and westbound roadways at 12 locations, for a total of 24 pavement-shoulder installations. A steel rod passes downward from the pavement or shoulder surface to each plate through a steel casing pipe which is plugged at the surface to keep out dirt and water, for use in determining plate elevations. Elevations are determined with an engineering level and rod, and referenced to six permanent benchmarks installed so that settlement plate locations are in no instance more than 500 feet distant. Elevation measurements are being made every few weeks during the freezing season, and once in midsummer.

Frost depth is being monitored principally with resistance-type gages spaced at one-inch intervals to a depth of 48 inches below the surface(4). The presence of frost is indicated by a major change in soil resistance at frost depth. A sketch of a frost gage installation is shown in Figure 17. Resistance measurements are made by hand with an AC bridge. Resistances also are being monitored at two-hour intervals by a Bristol multi-channel recorder at one location during portions of the freezing season. The resistance-gage frost measurements are supported by temperature measurements with copper-constantan

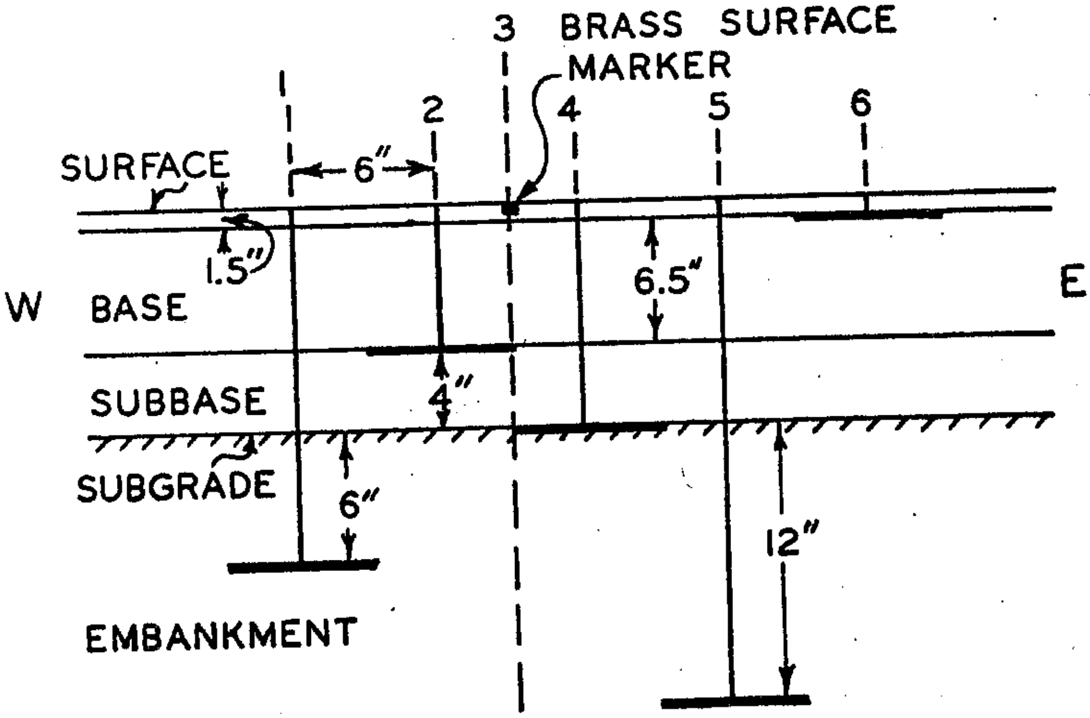


Figure 16. Settlement plate installation.

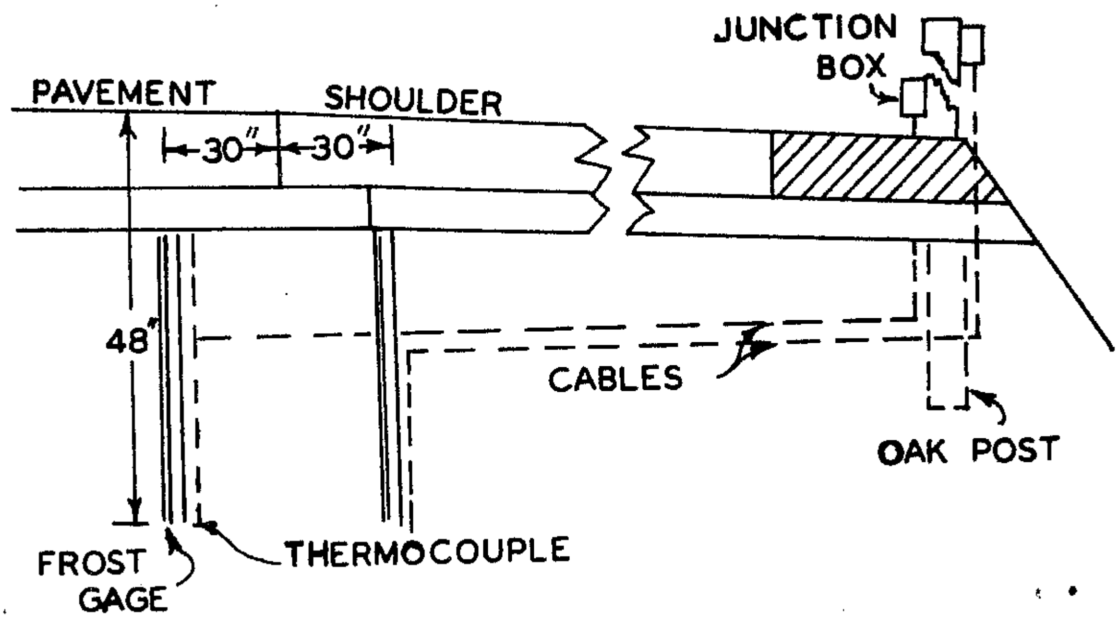


Figure 17. Frost gage installation.

thermocouples installed at 4-inch intervals to a depth of 48 inches below the surface, about an inch away from each frost gage. Temperatures are measured at the same time the frost gages are monitored, with a Leeds and Northrup potentiometer. Gandahl frost gages (5) are installed at two locations about two feet from the resistance frost gages as an additional frost-depth check. The Gandahl gage is a liquid column calibrated to read both inches and centimeters of depth below the surface. Frost depth is determined by checking the depth below the surface at which the liquid column is frozen.

RESEARCH MEASUREMENTS DURING CONSTRUCTION

A research observer was present on the site continuously during construction of the pavement and shoulders, beginning with the fine grading of the pavement subgrade and ending with the placement of the topsoil on the shoulder berms. Notes were made on all construction operations and material usage. Quality control sampling and testing procedures were observed, and installation of the instrumentation was supervised.

Dry densities and moisture contents of the upper 6 inches of embankment soil were determined at 300-foot intervals in both pavement and shoulder areas immediately prior to placement of the next succeeding structural layer. Measurements of moisture and density also were made at numerous locations in the shoulder base course materials following compaction. Nuclear testing equipment was used for these measurements. A summary of the data that were obtained in the subgrade soil measurements is shown in Table 4 presented earlier in the report.

MEASUREMENTS FOLLOWING CONSTRUCTION

During the year and a half that has followed construction and opening of the experimental section to traffic, a considerable quantity of temperature and frost penetration data has been obtained, and vertical movements of the pavements and shoulders have been measured at frequent intervals. Two detailed surveys of the condition of the outside shoulders have been made. The general condition of the inside shoulders has been observed but not recorded in detail. Numerous cores have been taken from the BAM, CAM, and PAM shoulders, and their condition examined. Roughometer measurements have also been made and roughness values recorded for future reference.

Temperature and frost.--Temperature and frost data obtained for the experimental project since construction are summarized in Figures 18a and 18b, and in Tables 5, 6, and 7. Figure 18a and 18b are cumulative freezing degree-day curves for the joliet area for the winters of 1967-68 and 1968-69 (6). A freezing degree-day is a day in which the mean between the maximum and minimum temperatures for that day is one degree below freezing. The curves were constructed from U. S. Weather Bureau data for Joliet. The zero axis on the charts is an arbitrary line representing the curve origin and a time scale. The period covered in the charts extends from November 1 through the first week of March. Portions of the cumulative curves with a positive slope (upwards to the right) are days with mean temperatures above freezing, and portions with a negative slope are days with the mean temperature below freezing.

It will be seen in Figure 18a that two distinct freezing cycles occurred during the winter of 1967-68. The first freeze produced 427 freezing degree-days, and the second produced 220 freezing degree-days. The net total for the winter was 573 freezing degree-days. In the period between the two freeze

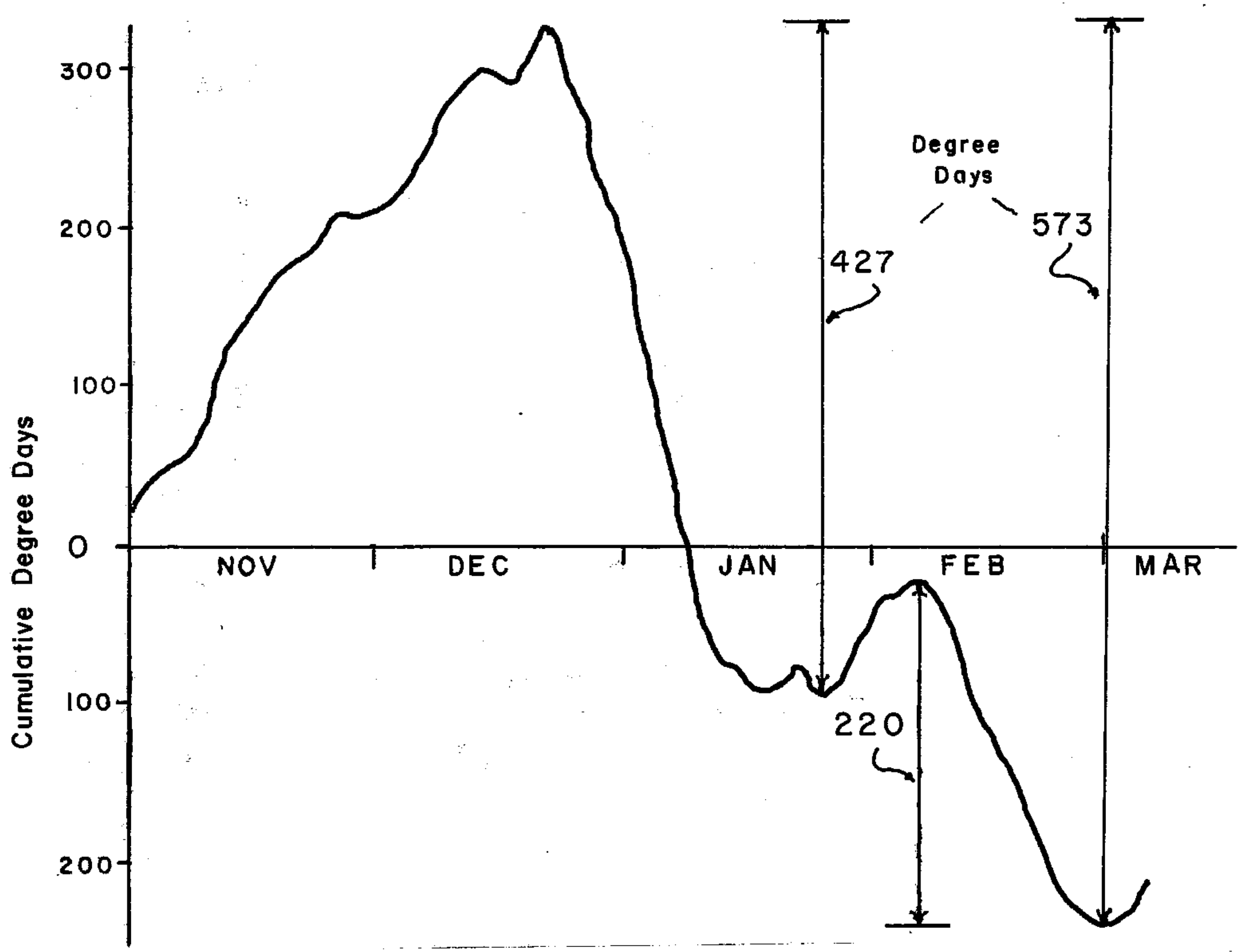


FIGURE 18a. Freezing Index for Joliet, 1967-68.

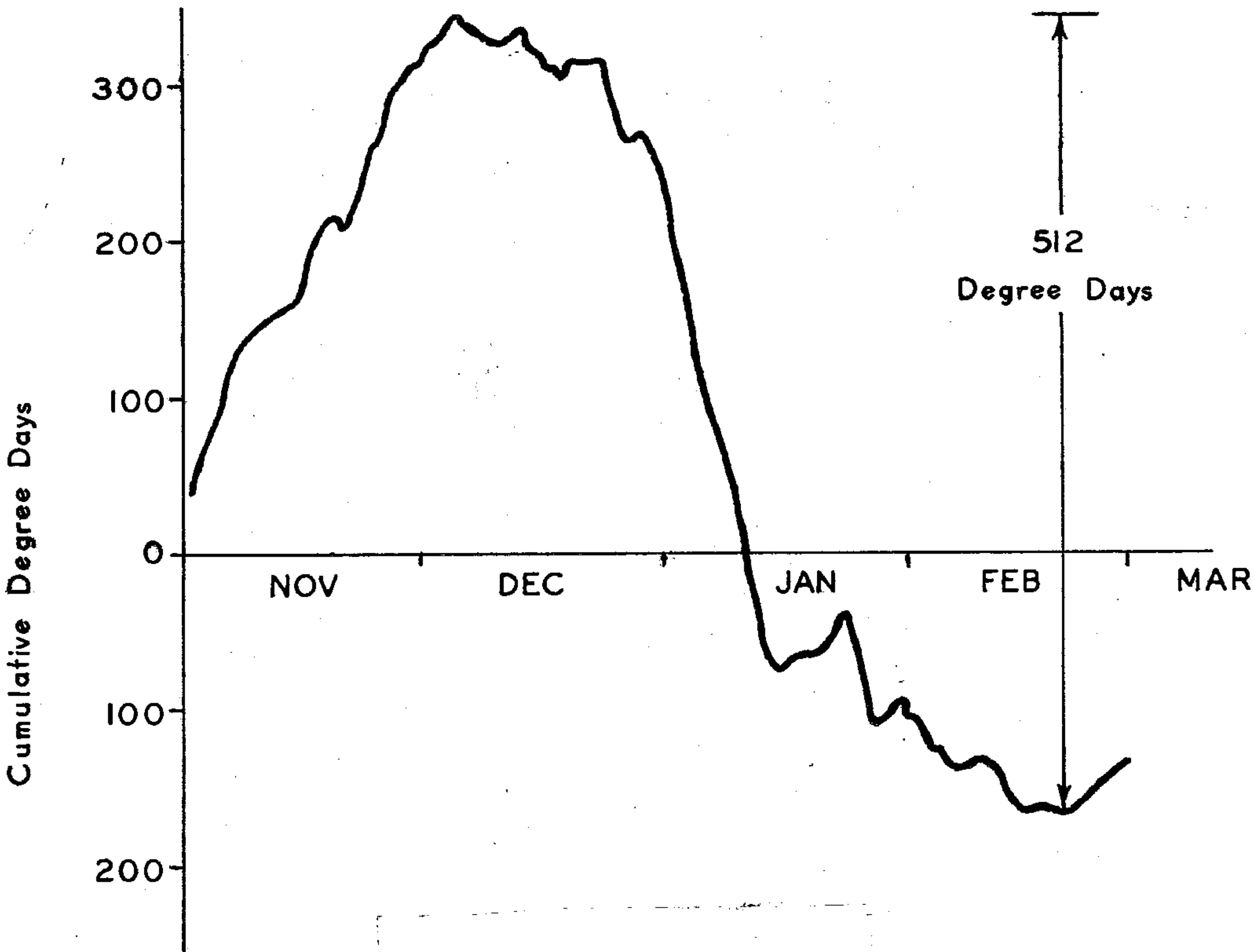


FIGURE 18b. Freezing Index for Joliet, 1968-69.

TABLE 5

MONTHLY TEMPERATURES AND PRECIPITATION AT JOLIET
JUNE 1967 THROUGH FEBRUARY 1969

Month	Temperature			Precipitation		
	Max. (F)	Min. (F)	Mean (F)	Total (in.)	Snowfall (in.)	Snow Depth (in.)
June (67)	83.7	61.9	72.8	4.08	-	-
July	83.0	58.5	70.8	2.70	-	-
Aug.	81.1	57.7	69.4	3.23	-	-
Sept.	76.3	52.3	64.3	5.81	-	-
Oct.	64.4	45.0	54.7	6.70	3.0	0.0
Nov.	46.4	31.2	38.8	2.02	1.0	1.0
Dec.	38.4	24.1	31.3	3.47	3.3	3.0
Jan. (68)	31.7	17.1	24.4	0.93	3.3	4.0
Feb.	35.0	15.3	25.2	1.28	2.5	2.0
Mar.	56.4	32.7	44.6	1.03	1.0	1.0
Apr.	65.4	42.5	54.0	2.33	-	-
May	70.4	48.4	59.4	2.96	-	-
June	85.4	61.5	73.5	4.35	-	-
July	86.0	63.0	74.5	1.46	-	-
Aug.	86.0	63.4	74.7	5.67	-	-
Sept.	78.4	54.6	66.5	4.30	-	-
Oct.	68.4	43.8	56.1	0.74	-	-
Nov.	50.5	34.6	42.6	3.96	T	0.0
Dec.	38.0	20.5	29.3	1.71	5.0	4.0
Jan. (69)	29.5	12.6	21.1	1.85	6.0	7.0
Feb.	37.8	23.8	30.8	0.07	T	T

TABLE 6

FROST DEPTH BENEATH THE SURFACE BY
LOCATION AND FREEZE CYCLE

Station	Design	Frost Depth by Freeze Cycle 1967-68 1 1/ (in.)	2 1/ (in.)	1968-69 (in.)
495+00				
E.B. Pavement	PCC/BAM	27	18	30
E.B. Shoulder	BAM/B	28	14	14
W.B. Shoulder	BAM/E	30	19	32
548+00				
E.B. Pavement	PCC/PAM	28	21	24
E.B. Shoulder	PAM/B	26	16	25
W.B. Shoulder	PAM/E	27	18	28
626+00				
E.B. Pavement	PCC/CAM	34	32	33
E.B. Shoulder	PCC/B	36	31	34
W B. Shoulder	PCC/E	32	32	34

1/ Numbers refer to freeze cycle
1 = 427 freezing degree-days
2 = 220 freezing degree-days
In 1968-69 there was only one freeze cycle which produced 512 freezing degree-days.

TABLE 7

NUMBER OF FREEZE-THAW CYCLES BY LOCATION
AND DEPTH BELOW THE PAVEMENT SURFACE
1967-68

Station	Design 1/	Depth Below Pavement Surface (in.) 12	18	24
495+00				
E.B. Pavement	PCC/BAM	3+	1	1
E.B. Shoulder	BAM/B	3+	1	1
W.B. Shoulder	BAM/E	2	1	1
548+00				
E.B. Pavement	PCC/PAM	2	2	1
E.B. Shoulder	PAM/B	2	1	1
W.B. Shoulder	PAM/E	2	2	1
626+00				
E.B. Pavement	PCC/CAM	2	2	1
E.B. Shoulder	PCC/B	2	2	1
W.B. Shoulder	PCC/E	2	2	2

1/ E of PCC/E refers to earth subgrade; B refers to Type B subbase.

cycles during late January, frost was indicated by the gages on the project to have totally disappeared at Stations 495+00 and 548+00, but not at Station 626+00. It will be seen in Figure 18b that only one major freeze cycle occurred in 1968-69, producing 512 freezing degree-days. Frost was present continuously in the embankment soils at the frost gage sites from December 1968 to March 1969. Measured frost depths at each of nine locations are shown in Table 6 for the three major freeze cycles that have been noted thus far. It will be noted that at Station 626+00, where frost did not completely disappear during the January thaw in 1968, frost depths were greater than at the remaining stations during the second freeze cycle. It will also be noted that differences in frost depth occurred between locations for a given number of freezing degree-days. These differences probably are associated with differences in pavement and shoulder type, and with the microclimate at the individual sites.

A count of freeze-thaw cycles that occurred at various depths beneath the surface of the roadway during the winter of 1967-68 is summarized in Table 7. As would be expected, the greatest number of freeze-thaw cycles was found to occur at the least depth below the surface.

Pavement and shoulder movements.--Vertical changes in position of the settlement plates in relation to each other and to the surface markers at the individual test sites are of interest in that they reflect changes that take place in the thicknesses of the pavement components, and also in the upper layer of subgrade soil. The time period of the study thus far extends from December 1967, when observations began, to April 1969. This period includes two freezing seasons and the intervening summer season. The data that have been recorded up to the present indicate that expansions commonly in the order of .02 to .03 feet have taken place in the upper portion of the embankment under both pavement and shoulders during the freeze cycle. If expansions have taken place in the structural components of the pavements and shoulders in freezing, they have not been identifiable. No trends of expansion of the embankment soil in relation to the type or thickness of cover have been observable within the limits of the precision with which plate elevations have been read.

Table 8 has been prepared to show the changes in surface elevation of the pavements and shoulders that have taken place under frozen and unfrozen conditions since the first elevation readings were made in December 1967. While the readings at all of the sites do not indicate that the movements are consistently in one direction or another, it will be seen that the pavements and shoulders generally have moved upward together under frozen conditions and downward when the frost has left the ground. A tendency appears to exist for the shoulders to move upward slightly more than the pavements. A slight tendency also appears to exist for both pavements and shoulders to remain above the original positions; however, there are some significant variations from this tendency. Finally, it will be noted that the total movements have been small except in isolated instances.

Outward movements of the shoulders with respect to the pavements have been slight to date.

Shoulder cracking.--For analytical purposes, the cracking that has been observed in the shoulder surfaces during condition surveys is being grouped into three categories:

(1) Transverse cracking

(2) Longitudinal cracking

 (a) near the pavement-shoulder joint

 (b) near the outer shoulder edge

TABLE 8

CHANGES FROM ORIGINAL SURFACE ELEVATIONS OF PAVEMENT AND SHOULDERS BY TIME AND FROZEN OR UNFROZEN CONDITIONS

Station	Design		Sealed Joint	1968				1969			
				Frozen		Unfrozen		Frozen		Unfrozen	
	Pavt.	Shldr.		Pavement	Shoulder	Pavement	Shoulder	Pavement	Shoulder	Pavement	Shoulder
						Eastbound					
462+50	P/CAM	CAM/B	Yes	+.01	-.06	-.03	-.11	+.03	-.07	0	-.08
464+50	P/CAM	CAM/B	No	-.04	-.02	-.05	-.03	-.01	+.02	-.05	-.02
487+00	P/BAM	BAM/B	Yes	+.01	+.02	-.02	0	-.03	0	-.04	-.01
495+00	P/BAM	BAM/B	No	+.01	+.02	-.01	-.01	-.01	0	-.04	-.03
537+50	P/CAM	CAM/B	Yes	-.01	+.02	-.02	0	+.03	+.09	0	+.03
542+00	P/CAM	CAM/B	No	+.01	+.01	-.01	-.01	+.03	+.04	+.01	+.04
548+00	P/PAM	PAM/B	Yes	+.05	+.04	+.03	0	+.06	+.01	+.05	-.03
553+50	P/PAM	PAM/B	No	+.02	+.03	0	0	+.04	+.04	0	0
619+00	P/CAM	PCC/B	Yes	+.02	+.03	0	+.01	+.06	+.08	+.01	+.01
626+00	P/CAM	PCC/B	No	+.02	+.02	+.01	0	+.06	+.05	+.01	0
647+00	P/PAM	BAM/B	Yes	+.05	+.04	0	0	+.06	+.04	+.03	+.04
649+50	P/PAM	BAM/B	No	+.02	+.03	+.01	0	+.03	+.06	+.01	+.01
						Westbound					
462+50	P/CAM	CAM/E	Yes	+.01	0	-.01	-.03	+.02	+.01	-.02	0
464+50	P/CAM	CAM/E	No	-.03	-.02	-.04	-.04	-.02	+.01	-.07	-.03
487+00	P/BAM	BAM/E	Yes	+.01	+.03	-.03	-.03	-.02	-.02	-.04	-.06
495+00	P/BAM	BAM/E	No	+.01	+.01	-.01	-.01	+.02	+.03	-.05	-.04
537+50	P/CAM	CAM/E	Yes	+.01	0	-.01	-.02	+.04	+.04	-.01	0
542+00	P/CAM	CAM/E	No	0	0	-.01	-.01	+.03	+.05	+.02	+.03
548+00	P/PAM	PAM/E	Yes	+.02	+.03	0	+.01	+.04	+.05	+.02	+.02
553+50	P/PAM	PAM/E	No	+.02	+.02	+.01	+.01	+.06	+.07	+.02	+.05
619+00	P/CAM	PCC/E	Yes	+.03	+.03	-.01	-.03	+.06	+.02	-.03	-.07
626+00	P/CAM	PCC/E	No	+.01	+.02	+.01	-.02	+.11	+.03	+.05	-.04
647+00	P/PAM	PAM/E	Yes	-.04	+.03	-.05	+.02	-.01	+.08	-.03	+.05
649+50	P/PAM	PAM/E	No	+.03	+.03	+.01	+.02	+.06	+.06	+.04	+.04

Original readings taken under frost-free conditions in December 1967.
Plus values show upward movements; minus values show the reverse.

(c) in the mid-area of the shoulder

(3) Area cracking

(a) alligator-type cracking, or structural failure in the BAM

(b) other complex cracking, or structural failure

Table 9 has been prepared to show the cracking characteristics of the various shoulder paving materials as indicated by the most recent condition survey which was made in April 1969. All cracking is reported in lineal feet per 1000 lineal feet of shoulder, except for the area cracking which is reported in square feet per 1000 lineal feet of shoulder. The data shown are for the outside shoulders only; the inside shoulders were not examined in sufficient detail to be included in the analysis. In addition, data from one section of outside shoulder of BAM on earth subgrade that experienced almost total failure associated with lift separation in the bituminous-aggregate material have been eliminated from consideration. A soil film on the layer interfaces, which probably formed during a long time-lapse that occurred between the placing of layers, is believed to have been the major cause of the failure. It can be seen that: (1) the BAM shoulders have been subject to a considerable amount of area cracking; (2) the CAM and PAM base shoulders have been subject to a considerable amount of longitudinal and transverse cracking, and the PAM to some area cracking in addition; and (3) the PCC shoulders have been subject to a limited amount of transverse cracking even though contraction joints were installed at 20-foot intervals.

Except in one test section of BAM on earth subgrade where an obvious lift separation and attendant structural failure was widespread, all area cracking in the BAM has been confined to the outer one half, and principally to the outer one third, of the shoulder area.

The longitudinal cracking that has occurred over major portions of the CAM and PAM shoulders lies within a few inches to a foot of the pavement edge.

The area cracking in the PAM shoulders has taken place in the space between the pavement edge and the longitudinal crack that has formed close to the edge.

It is obvious from Table 9 that the PCC shoulders on the experimental project are in a distinctly better condition than any of the other types under observation.

Table 10 has been prepared to explore the relationship of subbase to the cracking that has occurred in the shoulders thus far. It will be noted in the table that with respect to possible relationships of cracking with type of shoulder subbase material or with the presence or absence of shoulder subbase: (1) transverse cracking does not seem to be importantly related to subbase type, or to the presence or absence of subbase; (2) the longitudinal cracking in the vicinity of the pavement-shoulder joint that has occurred almost exclusively in the CAM and PAM shoulder sections does not seem to bear a strong relationship to type of subbase materials, or to the presence or absence of subbase; (3) longitudinal cracking at mid-shoulder is generally more prevalent on the Type A (sand) subbase; (4) longitudinal cracking at the outer edge of the shoulder is more prevalent where the shoulder base is on sand or earth; and (5) area cracking, which is confined principally to the BAM and PAM sections, is most prevalent where the subbase was not used.

No evidences of outward movement of the shoulders indicative of down-slope movements have been discernible.

The outcome of an exploration of relationship between sawing and sealing the pavement-shoulder joint and longitudinal cracking in the vicinity of this

TABLE 9

CRACKING CHARACTERISTICS OF SHOULDER MATERIALS
(Outside Shoulders Only)

	Transverse Cracking	Longitudinal Cracking Inner Edge	Longitudinal Cracking Mid-Shoulder	Longitudinal Cracking Outer Edge	Area Cracking
	(ft./1000 lineal ft. of shoulder)				(sq. ft./1000 ft.)
BAM	5	1	2	9	530
CAM	121	323	3	77	13
PAM	233	412	67	215	175
PCC	57	0	0	0	0

TABLE 10

RELATION OF SUBBASE USE TO SHOULDER CRACKING
(Outside Shoulders Only)

Base Material	Subbase Type 1/	Transverse Cracking	Longitudinal Cracking Inner Edge	Longitudinal Cracking Mid-Shoulder	Longitudinal Cracking Outer Edge	Area Cracking
		(feet per 1000 lineal feet of shoulder)				(sq. ft./1000 ft.)
BAM	A	19	9	4	14	654
	B	0	0	0	15	237
	C	0	0	6	0	308
	E	9	0	6	15	2008
CAM 3/	A	135	226	11	41	0
	B	135	321	0	35	0
	C	108	554	0	39	116
	E	107	281	7	104	0
PAM	A	255	547	202	253	67
	B	214	393	0	71	97
	C	206	335	105	9	186
	E	257	401	49	444	302
PCC	A	74	0	0	0	0
	B	28	0	0	0	0
	C	47	0	0	0	0
	E	74	0	0	0	0

1/ A = Type "A" subbase; B = Type "B" subbase; C = Type "C" subbase; E = No subbase

2/ Area Cracking is in square feet per 1000 lineal feet of shoulder. The BAM/E (No subbase) value does not include one section which is out of test. Including this section would increase the value to 4026 square feet.

3/ Some of the cracking along the pavement edge (inner) has reverted to area cracking in one CAM/C test section.

joint, is shown in Table 11 for the April 1969 survey. It can be concluded from the data presented in this table that sealing the pavement-shoulder joint was effective in reducing the amount of longitudinal cracking near this joint in the PAM and CAM materials, but was not essential in the BAM and PCC materials where this type of cracking has not developed. Sealing will be seen not to have been totally effective in the PAM and CAM shoulders where some cracking has developed in the sealed areas.

Durability.--Although no quantitative measurements have been made, observations at the interface of pavement and shoulder have shown loose particles of aggregate to be present in the PAM and CAM mixtures, indicative of some loss in durability. Coring will be done at a later date to explore the areal extent of this apparent loss of durability. Cores taken in interior shoulder locations have shown no lack of durability.

Moisture and density of subgrade soils.--Post-construction measurements of subgrade moisture and density were begun only recently following the delivery of special equipment for the purpose, and no information on these is currently available.

RESULTS AND RECOMMENDATIONS

The paved shoulders of the experimental section of I-80 east of Joliet have not shown, in their first two winters of service, strong upward differential movement relative to the adjoining pavement. This is at variance with the experiences elsewhere in northern Illinois that were major factors in causing present experimentation to be undertaken. Shoulder-pavement designs that had shown major differential movements were well represented in the I-80 experimentation. The subgrade soil is very similar to that at the other locations with respect to frost susceptibility. The major difference in the total roadway design between the experimental section and the sections that were

TABLE 11

RELATIONSHIP BETWEEN SEALING AND THE AMOUNT OF
LONGITUDINAL CRACKING NEAR THE PAVEMENT-SHOULDER JOINT
(Outside Shoulders Only)

Material	Sealed	Unsealed
	(ft./1000 lineal ft. of shoulder)	
BAM	0	3
CAM	176	470
PAM	227	597
PCC	0	0

constructed earlier was the change from the use of an unstabilized granular subbase material under the mainline pavement to the use of granular mixtures stabilized with asphalt, cement, and lime-flyash. It is believed that this has removed an important source of water that contributed to the earlier problems.

The structural performance of the bituminous-aggregate mixture (BAM) on the I-80 experimental project has been inferior to that which has been experienced elsewhere in Illinois. It is strongly suspected that construction aberrations unique to the experimental project were responsible mostly for the poor showing of the BAM as a structural material. Over a considerable portion of the areas where outright failure took place, distinct planes of separation were found between construction lifts. The presence of a soil film on the layer interfaces, which construction records reveal probably formed because of a considerable time-lapse between the placing of layers, is believed to have been a major contributor to the failures.

It was further observed that much of the structural failure in the BAM sections took place near the outer edges where the structural design called for thicknesses of 6-7 inches, and where constructed thicknesses have been noted to be below plan thicknesses. Whether or not construction to full-plan thickness would have prevented the structural failures can only be conjectured upon, but it appears certain that little reserve strength would exist even at full thickness.

The shoulder pavements that include cement-aggregate mixtures (CAM) and pozzolan-aggregate mixtures (PAM) are showing an extensive amount of the longitudinal cracking near the pavement-shoulder joint that was found prevalent previously in shoulders where these mixtures were used. The experimentation thus far has not suggested ways of avoiding this cracking.

The performance of the portland cement concrete (PCC) is significantly better than that of any of the other types. While service-life projections of perhaps 20 years based on less than 2 years of service cannot be made with a truly high degree of confidence, it would seem that of the various types of paved shoulders included in the experiment, the PCC shoulders may have the best chance of serving the longest time without need for special maintenance.

The presence of the open-graded subbase materials placed under certain of the shoulders, and extended through the side slopes for drainage, appears to be contributing to better overall performance of the shoulders. Problems encountered in keeping the sand subbase in place during succeeding construction operations discourage its consideration for future construction usage.

The hot-poured rubber-asphalt joint sealant is retarding the development of longitudinal cracking at the pavement-shoulder joint of the CAM and PAM sections. It has had no measurable effect on the behavior of the BAM and PCC shoulders up to the present time. More experience is needed before any possible beneficial effect when used with BAM and PCC shoulders can be determined.

The following additional observations also have been made:

Very dry and very dense conditions can exist in the soil immediately below subgrade level at the time of placement of shoulder structures. This suggests a potential for differential heave of the shoulder with respect to the pavement through moisture gain if the subgrade soil under the pavement is of appreciably higher moisture content.

The pavement and shoulders together move upward when frost penetrates the earth subgrade. Observed movements have been mostly of the order of 0.02 to 0.04 ft., although somewhat greater movements occasionally have been recorded. Shoulders exhibit a tendency to show greater movement than the pavement.

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